

# The study of the influence of deviations of the arc energy parameters on the defects formation during automatic welding of pipelines

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**Abstract.** Modern quality management systems for welding products are based on procedures to minimize the likelihood of typical defects. The reasons for deviations of the energy parameters of the welding process include disturbances along the length of the arc or its breaks associated with a spasmodic change in the electrode wire feed speed, violation of the power circuit with the welded product, mains voltage, and shielding gas consumption. To establish a connection between deviations of the welding parameters with the quality indicators of the welded joints, a model for the formation of a weld seam under the conditions of technological disturbances has been developed. It is shown that the formation of the crater depends not only on the duration of the arc break, but also on the welding parameters. It has been established that in the presence of lateral oscillation of the electrode, an arc break significantly increases the undercut, the maximum depth of which moves to the center of the groove to the cutting center as the break duration increases. Whereas an increase in the amplitude of lateral oscillation of the electrode causes a significant increase in the depth of the crater.

## 1. Introduction

Taking into account the consequences of accidents and failures during operation, trunk pipelines are classified as hazardous production facilities. According to the data from the regulatory authorities, more than 85% of accidents and disasters at hazardous technical facilities, including pipelines, are due to defects of welded joints, including leakages, due to this the problem of ensuring the quality of welded joints is of immediate interest.

Modern quality management systems for welding products are based on procedures to minimize the likelihood of typical defects. Welding monitoring procedures, which have already become an integral part of scientific and technical support for the construction of trunk pipelines [1], have become an effective tool for this. Monitoring procedures provide monitoring of energy parameters of welding processes, forestalling and prevention of causes of non-compliance of welded joints with the requirements of technical documentation, and control of their elimination. At the same time, monitoring procedures make it possible to implement a number of requirements for documenting work performed. This is achieved by connecting to the modern welding equipment special recorders [2] with the appropriate software. The development of such systems for monitoring, recording and



documenting the parameters of the welding process is carried out by a number of domestic high-tech science-intensive enterprises, and the systems can be built into modern digital power sources or made in the form of separate blocks. It can be stated that the most popular systems for monitoring of welding processes are used to document their parameters, as well as to analyze the consumption of materials, work time, register parameters beyond tolerances, and discipline welders. Unfortunately, so far none of the systems responds promptly to the main question: what consequences will the identified deviations lead to. Taking this into consideration, monitoring systems are needed that not only control and document the welding process, but also predict its results.

It should be noted that, despite attempts to predict the quality of welded joints according to the results of monitoring the parameters of welding processes, undertaken as at the beginning of this century [3] as well as later [4], operational quality forecasting systems that can be used on a job site don't exist, since an array of information is needed not only about defects in welded joints, but also about the causes of their occurrence. Therefore, for the operational forecasting of the quality of welded joints to become an effective tool for preventing defects formation of welded joints, additional studies of the significance of individual factors and phenomena, their influence on quality indicators, are needed to create and include in the structure of the forecasting module of a complete process model, as well as an information storage with the necessary filters.

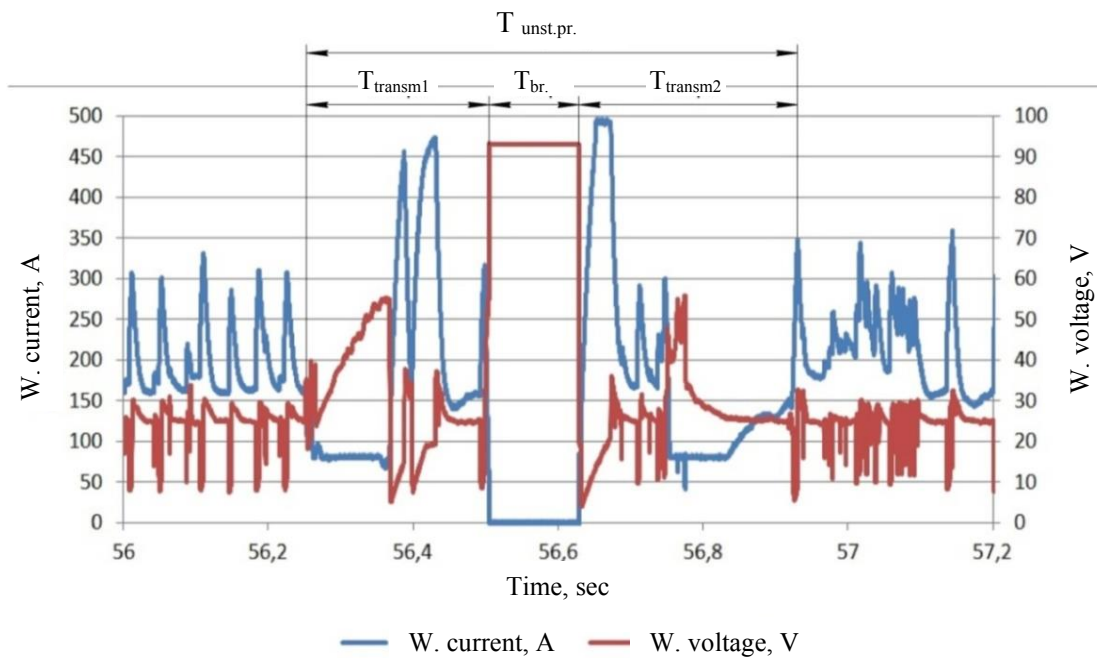
## **2. Materials and Methods**

One of the effective tools for ensuring a consistently high quality of welded joints is the use of automatic welding methods. However, the processes of automatic orbital welding of pipelines cannot ensure defect-free welding, since the main causes of defects are difficult to predict deviations in the energy parameters of the welding process, or process disturbances due to poor preparation and assembly of joints for welding, the human factor [5].

The reasons for deviations of the energy parameters of the welding process include disturbances along the length of the arc or its breaks associated with a spasmodic change in the electrode wire feed speed, violation of the power circuit with the welded product, mains voltage, and shielding gas consumption. Among technology-based perturbations associated with poor preparation and assembly of joints for welding, it is necessary to highlight uneven edge beveling and the gap in the joint, displacement of the edges, etc.

Since monitoring is limited to measuring the current and voltage of the arc and information about the assembly of the joint, the task is to virtually reproduce the influence of sharp deviations of the current and voltage of the arc that occur during arc breaks and short circuits (Figure 1) on the formation of the weld pool and seam.

Breaks and short circuits of the arc are usually the causes of violation of the formation of the seam, which lead to the appearance of extremely dangerous and unacceptable welding defects in the form of lack of fusion occurring both between the beads of the multi-pass seam and at the borders of the seam with the edges of the parts, and lack of root penetration [6, 7]. These defects are very similar in many respects, since they exhibit themselves in the local absence of fusion between the weld metal and the base metal or between the layers of the weld metal. As noted in [8], the occurrence of lack of fusion at the site of the craters of the previous layer is due to the limited penetrating ability of the arc burning in the partially filled prepared edges, as well as the shape of craters having a significant depth relative to their diameter. Lack of fusion is formed by incomplete inflowing of the molten bath into the crater, which is hindered by the surface tension and the gas pressure in the closed cavity of the crater. Under stick electrode welding with flux-cored and self-shielding wire, craters are filled with slag under the flux layer, which leads to the appearance of slag inclusions in the weld. Lack of root penetration occurs also due to the penetrating ability of the arc.



**Figure 1.** A fragment of the result of monitoring the voltage and current of the arc during arc welding:

$T_{\text{unst.pr.}}$  – the duration of the unstable process,  $T_{\text{br.}}$  – the duration of the arc break,

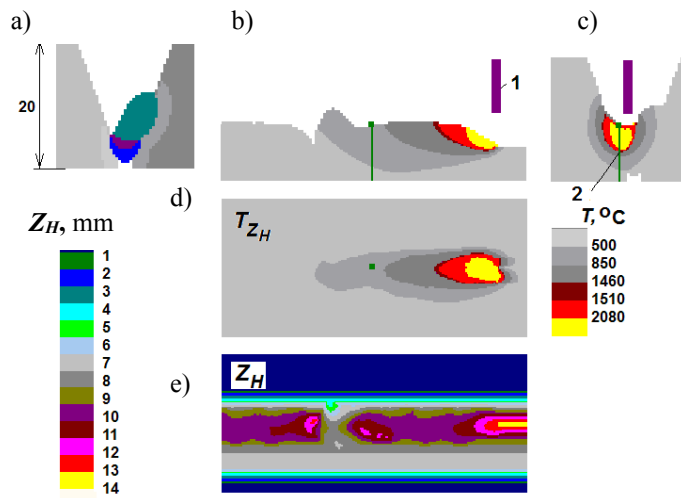
$T_{\text{transm1}}$  – the duration of the transition from the stable process to the break;

$T_{\text{transm2}}$  – the duration of the transition from a break to a stable process.

The solution to the problem of predicting the appearance of defects is based on modeling of the process with deviations of parameters detected during monitoring. Physical and mathematical modeling of welding is an effective tool to take into account the influence of welding parameters relevant to the quality of welded joints. Since monitoring is limited to measuring the current and voltage of the arc and information about the assembly of the joint, the task is to virtually reproduce the influence of sharp deviations of the current and voltage of the arc that occur during arc breaks and short circuits on the formation of the weld pool and seam. For this, a physical and mathematical model presented in [9] should connect the monitoring parameters with defects in weld formation, at the core the model are the equations describing the arc with monitoring data, heat transfer and formation of the surface of the weld pool and weld.

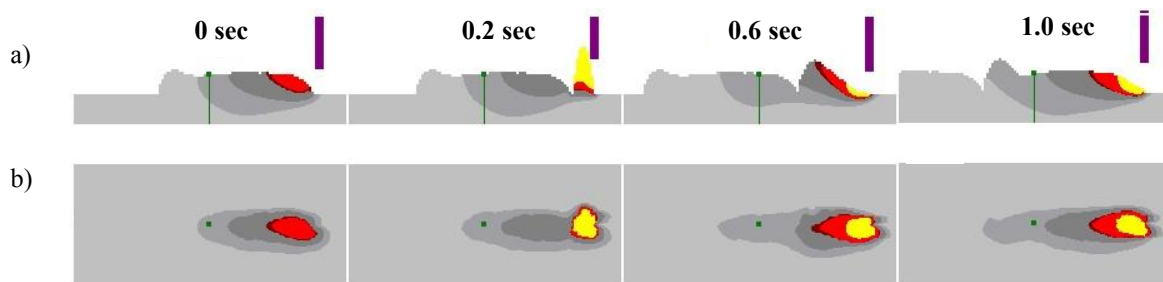
### 3. Results

The simulation results of the effects of short-term arc breaks on the formation of the weld are shown in Figure 2.



**Figure 2.** The results of simulating a short-term (0.2 s) arc break on the formation of a weld: a) the shape of the cross section of the joint; b) longitudinal section of the weld pool and seam; c) the limiting distribution of temperature in the cross section; d) temperature distribution on the surface  $Z_H$  of the metal; e) topography of the surface relief of  $Z_H$  metal; 1 – electrode, 2 – gravity vector.

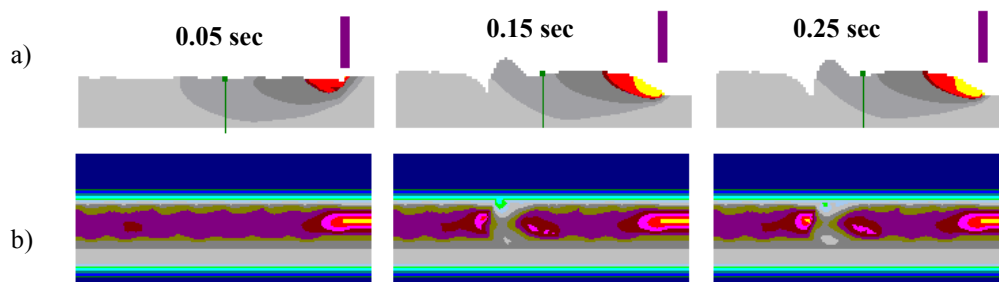
With the specified parameters of the welding mode, an arc break of 0.2 s caused the formation of a crater in the weld bead with the maximum possible depth. Figure 3 shows the phases of formation of such crater.



**Figure 3.** The phases of the formation of the crater in the weld bead and the temperature distribution: a) in a longitudinal section in the plane of the central position of the electrode; b) on the surface of the edges and weld pool.

Under narrow and deep groove welding, a short weld pool is formed due to the powerful heat removal, since it is surrounded on three sides by cold metal [10]. Therefore, when the arc breaks, its size decreases rapidly, and the electrode moves away from it with a welding speed. If, at the moment of repeated arc initiation, the metal melting resumes outside the weld pool, a new weld pool begins to form, which does not fuse with the bath formed before the break. Because of this, the likelihood of lack of fusion when applying a subsequent bead increases sharply.

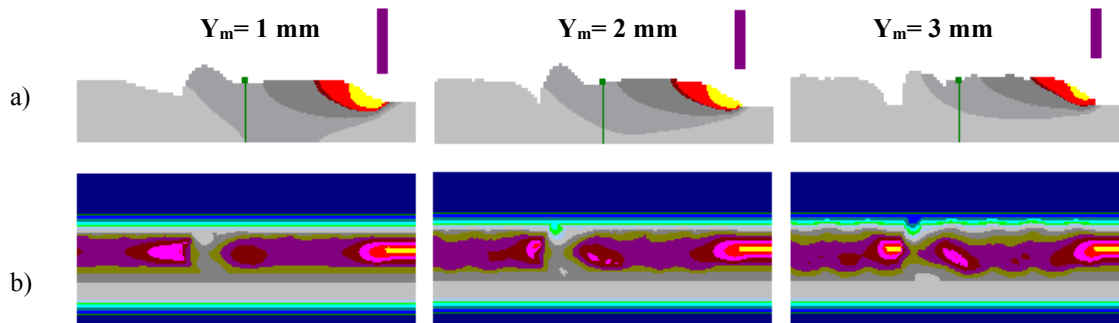
The consequences of this situation are presented in Figure 4.



**Figure 4.** Influence of the arc break duration on the crater shape in the weld bead: a) temperature distribution in the longitudinal section in the plane with the greatest crater depth; b) topography of the surface relief  $Z_H$  of weld.

With a short arc break duration, the crater does not actually occur due to the continuous existence of the weld pool. With a very long break in the arc, the crater turns into a bead with cracks.

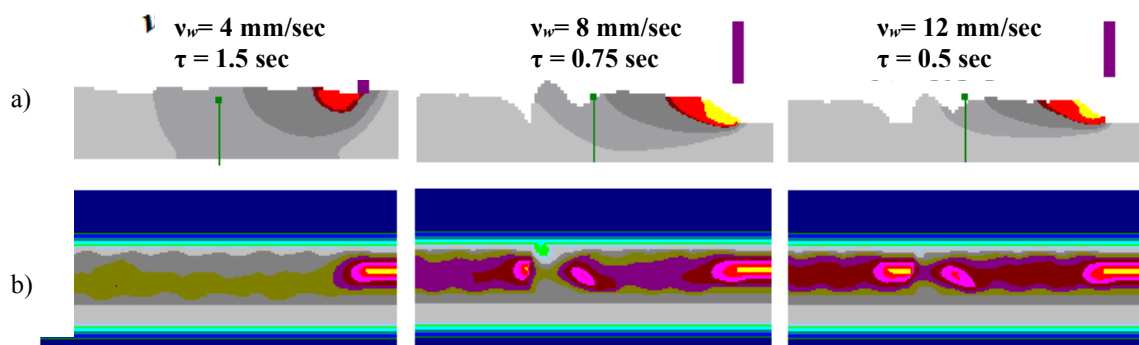
The formation of the crater depends not only on the duration of the arc break, but also on the welding parameters. An increase in the amplitude of lateral oscillation of the electrode causes a substantial increase in the depth of the crater (Figure 5).



**Figure 5.** Influence of the amplitude of lateral oscillation on the crater shape in the weld bead after arc break for 0.2 s: a) temperature distribution in the longitudinal section in the plane with the greatest crater depth; b) topography of the surface relief  $Z_H$  of weld.

Virtual studies have shown that the formation of the crater depends not only on the duration of the arc break, but also on the welding parameters. In the presence of lateral oscillation of the electrode, an arc break significantly increases the undercut, the maximum depth of which moves to the center of the groove as the duration of the break increases. An increase in the amplitude of lateral oscillation of the electrode causes a substantial increase in the depth of the crater.

Equally significant is the influence the oscillation period and the welding speed (Figure 6).



**Figure 6.** Influence of the welding speed  $v_w$  and the oscillation period  $\tau$  on the shape of the crater in the weld bead: a) temperature distribution in the longitudinal section in the plane with the greatest crater depth; b) topography of the surface relief  $Z_H$  of weld.

Therefore, to predict the likelihood of lack of fusion occurrence directly during the monitoring process, it is necessary to establish the dependence of the crater depth both on the duration of the arc break and on other parameters of the welding process, primarily on the shape of the beveling of the joint, taking into account its filling, spatial welding performance, arc power, and welding speed and parameters of lateral oscillations of the torch.

In this regard, in order to eliminate the drawbacks of existing monitoring systems, which are limited by registration of the process parameters beyond the specified limits and do not assess the possibility of defects formation in welds, it is necessary to develop a model that quantitatively relates monitoring data and welding process parameters with the likelihood of lack of fusion between the beads and edges of the multi-pass seam.

To establish the dependence between the stability of the energy parameters of the process of automatic orbital welding of pipelines and the quality of welded joints, a physical and mathematical model for the formation of a multi-pass weld is developed based on a system of equations describing the arc taking into account monitoring data, heat transfer, and the formation of the surface of the weld pool and weld.

#### 4. Conclusion

Numerical modeling of the crater's formation has shown that their depth depends not only on the duration of arc breaks, but also on many parameters of the welding process. However, for a more accurate forecast of the probability of occurrence of welding defects by the operational analysis of monitoring data, it is necessary to additionally establish the dependence of the crater depth both on the arc break duration and on other parameters of the welding process, primarily on the type of the beveling taking into account its filling and the spatial position of the welding machine, arc power, welding speed and parameters of the lateral oscillation of the torch. The developed physical and mathematical model allows us to solve this problem. However, for a more accurate determination of the position of the electrode in the groove, it is necessary to obtain an operational feedback, for example, using vision systems, described in detail in [11].

#### Acknowledgement

The assistance provided by the translator of the present article Ms. Natalia Karamysheva was greatly appreciated.

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